Final Report:
"Integrated Requirements Analysis
and Technology Roadmaps"
conducted for
NASA's Highly Reusable
Space Transportation (HRST) Program

submitted to
NASA's Marshall Space Flight Center (MSFC)
Advanced Concepts Office (PS 05)

prepared by
Strategic Insight, Inc.
Arlington, Virginia

October 6, 1997

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Executive Summary

In fiscal year 1997, Strategic Insight performed analytical studies for NASA's Highly Reusable Space Transportation (HRST) program, creating program documents which illuminated technical requirements and critical research opportunities. Studies were performed to structure and confirm HRST's evolving technical requirements, building on Marshall's Phase I work, which defined HRST system concepts, analytical tools and high-level issues for assessment in Phase II.

Specifically, Strategic Insight:

- Performed a requirements analysis to update "HRST: *An Advanced Concepts Study* -- Study Guidelines, Version 2.0 of January 22, 1996; only minor changes were recommended for the given parameters of interest to concept designers.
- Conducted mini-workshops during HRST Working Group meetings on April 14-15, 1997 and July 22-24, 1997; and,
- Created structures for technology road maps of candidate HRST concepts—both subsystem and end-to-end concepts—emerging from the 13 cooperative agreement projects.

Background/Introduction

In calendar year 1997, focused analysis was required so NASA could sharpen its guidelines and select high-payoff research and development options for the Highly Reusable Space Transportation—HRST—program. In particular, attention was needed along several established lines of investigation to further the maturity of candidate low-cost space launch concepts.

During the past 18 months, Marshall Space Flight Center (MSFC) managers initiated a comprehensive space transportation plan for the next 20+ years to reduce the cost of launching payloads to space and recapture the country's technical preeminence in space launch technologies. As the overall plan is implemented MSFC must develop a suitable HRST response, including critical subscale hardware experiments.

Assistance will be required to help define the proper path of action—using the results of HRST studies conducted by the private sector and academia such as this one—that will prove most useful to MSFC for the long haul.

The contractor's analysis amplifies MSFC's data base, providing a method of capturing technology ideas in the near term—the next 2-3 fiscal years—as HRST transitions from paper studies into proof of concept experiments with subscale hardware. The project specifics will hinge on the risk avoidance/technology optimization choices made by MSFC managers, but should involve the possibility of major technical advancements in the HRST mission (i.e., quantifiable, order-of-magnitude reductions in the cost of launching payloads to low earth orbit) and the involvement of the private sector and academia in the assessment of options identified in Phase III.

Proposal/Statement of Work

In calendar year 1996, Strategic Insight proposed to perform focused analytical studies for NASA's HRST program, creating program documents which illuminate technical requirements, critical research opportunities and programmatic relationships with other federal agencies and the private sector. Studies were to be performed to structure and confirm HRST's evolving technical requirements, simulation & test results and programmatic options. Such activities follow on from Marshall's earlier work, which defined HRST system concepts, analytical tools and high-level issues for assessment in Phase II and III.

Specifically, Strategic Insight proposed to provide key inputs to NASA by:

- performing an integrated requirements analysis to update existing HRST documentation[1];
- conducting mini-workshops during HRST investigations; and,
- creating critical technology road maps of candidate HRST concepts—both subsystem and end-to-end concepts—emerging from the 13 cooperative agreement projects with industry and academia.

The contractor's efforts would provide key inputs to confirm the payoff of HRST concepts as building blocks in MSFC's long range space transportation plans. Using data generated by the contractor, MSFC should be able to develop a portfolio of high-leverage research projects to support knowledgeable management decisions which will increase the chances of eventual success for HRST and provide strategic research signals to the private sector and other parts of the federal government.

The contractor would conduct these analyses and produce a written report with supporting documentation to preserve all findings.

1: "HRST: *An Advanced Concepts Study* -- Study Guidelines" Version 2.0 of January 22, 1996

Requirements Analysis

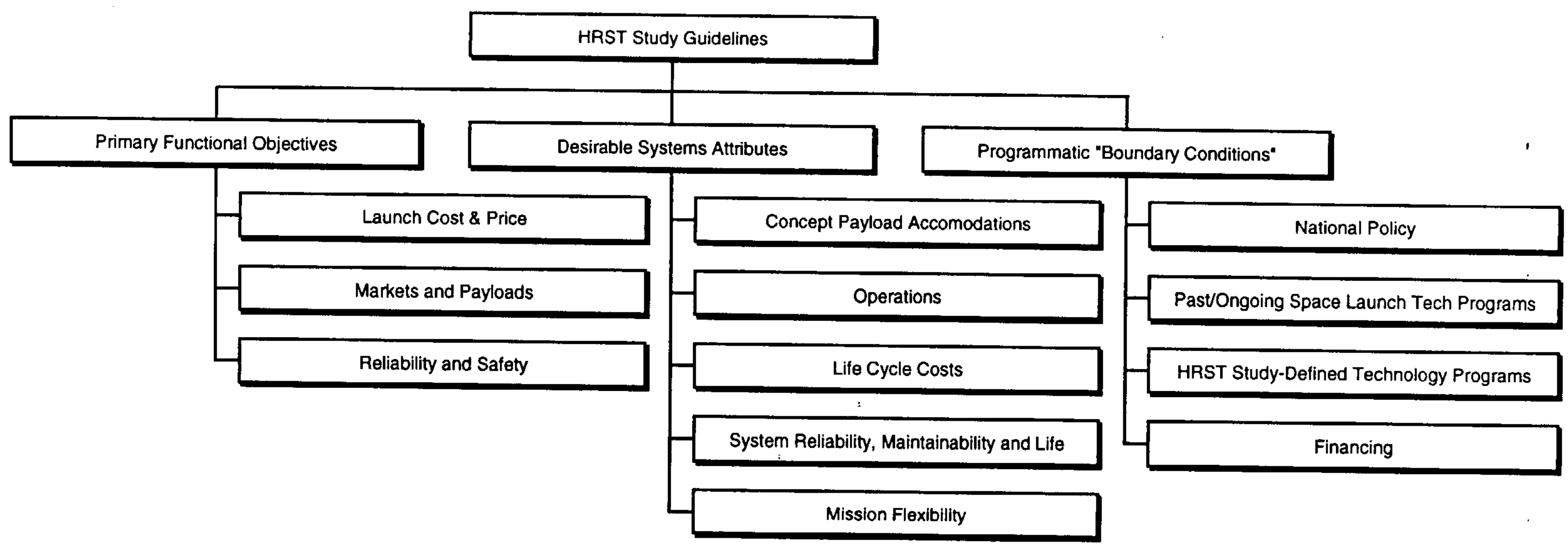
The requirements analysis to update "HRST: *An Advanced Concepts Study* -- Study Guidelines" was done sporadically from February through September, 1997, as warranted by meetings of the HRST working groups and/or for discussion in the technical interchange meetings. For group interaction, a general discussion of the parameters of interest was assembled and presented at the TIM in July; the charts themselves (noted as "HRST TIM - 13" through "HRST TIM - 25") are attached at the end of this section.

Given the diverse nature of the findings in the original document, it was a pleasant surprise that we could not find glaring omissions from any of the major sections.

Minor changes for parameters of interest to concept designers are recommended and summarized below, organized by section of the original document.

<u>Section</u>	<u>Comment/revision proposed</u>
Study Objectives	no change
Study Guidelines	no change
Primary Functional Objectives	Para. 1.2.2: consider adding specific mission/payload requirements for space manufacturing and space medicine
Desirable System Attributes	no change
Progammatric Boundary Conditions	no change
Supporting Information	Under Glossary of Acronyms, , consider adding the term "DDR&D" to denote the degree of difficulty of achieving research & development objectives; also consider adding language to the Glossary of Terms summarizing the following page at the end of this section, which was taken from a NASA requirements assessment form.

HRST Study Guidelines: 1996



Primary Functional Objectives

- **Only concepts/architectures with credible likelihood of meeting these objectives will be considered**
  - 1: Launch cost & price
    - consistent w/ CSTS conclusions
    - recurring ops cost/payload # $100-200
    - recurring ops price/payload # $300-400
  - 2: markets & payloads
    - CSTS civilian gov't, commercial, nat'l security payloads (continued)

Primary Functional Objectives

- 2: markets & payloads
  - CSTS civilian gov't, commercial, nat'l security payloads
    - private citizens
    - gov't military passengers
    - satellites, space materials
    - bulk materials
    - 'hazardous' materials
    - as a minimum, 100 nautical mile circular orbit at 28.5 degrees inclination
  - Reliability & Safety (continued)

Primary Functional Objectives

- Reliability & Safety
  - >99.99% against catastrophic loss
  - safe recovery & return of ‘precious cargo” 5X
  - fail-safe operations assured over land

Desirable System Attributes

- **Concept payload accommodations**
  - 20,000 to 40,000 pounds/10-20 MT
  - payload bay >6,000 cubic feet volume
  - payload bay > 15 feet/4.5 meters diameter...35 feet long
  - payloads 1,000-3,000 pounds to LEO with costs <$1,000 per pound

Desirable System Attributes

- **Operations**
  - launch rates: >50/year (once a week)
  - “all” orbit launch inclinations
  - launch from 100 n.m.i. to GEO altitudes with upper stages, etc.
  - self-sufficient LEO operations: 48 hours
  - infrastructure @ 200 vehicle-visits/week
  - <250 “direct charge” individuals on ground
  - all weather, rapid turn around operations

Desirable System Attributes

- **Life Cycle Costs**
  - adequate R.O.I.
  - recurring costs include infrastructure
  - “flight vehicle” costs < $1 Billion
  - recurring costs < $200 Million/year
  - recurring costs of flight vehicle hardware < $500K -- $1M per flight

Desirable System Attributes

- **Reliability, maintainability & life**
  - effective lifetime > 2,000 flights
  - MTBmaintenance ops > 200 flights OR
  - MTBmaintenance ops > 20 flights if costs are > 1--2% of value of vehicle
  - performance margins >> HRST reference vehicle

Desirable System Attributes

- **Mission flexibility**
  - operational vehicles capable of accepting launch assist or thrust augmentation systems
  - operational vehicles capable of sustaining science/exploration missions; being modular or expandable to new missions

Programmatic Boundary Conditions

- **National policy**
  - GATT compliance
  - U.S. National Space Policy
  - dual use technology, technology transfer
  - commercialization
- **Past, on-going space launch technology programs** (cont'd)

Programmatic Boundary Conditions

- **Past, on-going space launch technology programs** (cont'd)
  - "Access to Space" Option 3, all-rocket SSTO is baseline case
  - leverage comes from past studies whenever possible
- **HRST-defined technolgy programs**
  - mid-/far-term to TRL 6 by 2010/2015 (continued)

Programmatic Boundary Conditions

- **HRST-defined technolgy programs**
  - mid-/far-term to TRL 6 by 2010/2015
  - NASA R&D <$200-300M/year
  - dual use is good
  - multi-use is better
- **Financing**
  - 100% private for operational flight vehicles (continued)

Programmatic Boundary Conditions

- **Financing**
  - 100% private for operational flight vehicles
  - engineering development >50% private
  - technology demonstrations >25% private
  - gov't demos, "macro" infrastructure may be up to 100% gov't financed

REFERENCE

HIGHLY REUSABLE SPACE TRANSPORTATION

VEHICLE SYSTEM / TECH. WORKSHEET – DEGREE OF DIFFICULTY IN R&D

DDR&D	DESCRIPTION
A	**Very low degree of difficulty anticipated in achieving research and development objectives for this technology;** only a single, short-duration technological approach needed to be assured of a high probability of success in achieving technical objectives in later systems applications
B	**Moderate degree of difficulty anticipated in achieving R&D objectives for this technology;** a single technological approach needed; conducted early to allow an alternate approach to be pursued to be assured of a high probability of success in achieving technical objectives in later systems applications
C	**High degree of difficulty anticipated in achieving R&D objectives for this technology;** two technological approaches needed; conducted early to allow an alternate subsystem approach to be pursued to be assured of a high probability of success in achieving technical objectives in later systems applications
D	**Very high degree of difficulty anticipated in achieving R&D objectives for this technology;** multiple technological approaches needed; conducted early to allow an alternate system concept to be pursued to be assured of a high probability of success in achieving technical objectives in later systems applications

Mini-workshops

Strategic Insight participated in mini-workshops during HRST Working Group meetings on April 14-15, 1997 and the Technical Interchange Meeting (TIM) July 22-24, 1997. For the July TIM Strategic Insight moderated afternoon sessions during which concept designers briefed the current state of affairs in defining their specific technology goals and subsystems designs.

These workshops took the form of round-table discussions in most cases, and as such did not result in any written products per se. For the July TIM the charts shown in the following section (Technology Road Maps) were briefed to the group as a means of stimulating discussion between the participants during the afternoon workshops. At that time most of the concept designers had prepared information using the format described in the blank "Vehicle/System Technology Worksheets" charts—a few of which are provided for the record on the following pages.

The bulk of the materials available for discussion in the workshops have been provided by the concept designers to NASA directly and will not be duplicated here.

DRAFT FORMS

HIGHLY REUSABLE SPACE TRANSPORTATION

VEHICLE SYSTEM / TECHNOLOGY WORKSHEETS

SYSTEM ______________________________

DATA REFERENCE

NAME:
Organization:
Phone:
Fax:
e-mail:

May 1997

HIGHLY REUSABLE SPACE TRANSPORTATION

VEHICLE SYSTEM / TECHNOLOGY WORKSHEET

Form 1 (of 10)

- **VEHICLE SYSTEM NAME**
  - *Name*

- **VEHICLE SYSTEM TYPE**
  - *(List all that apply –SSTO, TSTO, HTHL, VTVL, VTHL, RBCC, All-Rocket, CPS, CCP, Electromagnetic, etc.)*
- **VEHICLE SYSTEM DESCRIPTION**
  - *Text - approximately Š 300 words*

- **RELEVANT PROPULSION AND OTHER SYSTEMS REQUIRED FOR HRLV OPERATIONS**
  - *List all that apply; reference existing HRST Propulsion Sysem Worksheets or append new sheets as required; could include thrust augmentation systems, launch assist systems, etc.*

<u>Data Reference</u>: NAME, Org., Phone, Fax, e-mail

HIGHLY REUSABLE SPACE TRANSPORTATION

VEHICLE SYSTEM / TECHNOLOGY WORKSHEET

Form 3A (of 10)

- **VEHICLE SYSTEM NAME**
  - *Name*

- **VEHICLE SYSTEM / TECHNOLOGY / COST SUMMARY DATA**

ITEM	MASS (kg)	OVERALL TRL	OVERALL DDR&D	INHERITANCE (HIGH/MED/LOW)	EST. COST ($,M) DDT&E	EST. COST ($,M) TFU	EST. COST ($,M) PER UNIT
– TOTAL HRLV (OR SYSTEM) – DRY	TBD	TBD	TBD	TBD	TBD	TBD	TBD
– TOTAL HRLV (OR SYSTEM) – GLOW	TBD	n/a	n/a	n/a	n/a	n/a	n/a

- **PAYLOAD CAPABILITY TO HRST GUIDELINE ORBIT (FOR HRLV VEHICLES OR SYSTEMS)**
  - _________ KG PER LAUNCH, DELIVERED TO 100 NM, 28.5 DEGREES
  - _________ M**3 PAYLOAD BAY VOLUME (WITH ______ meters = BAY LENGTH; ______ meters = BAY DIAMETER)
- **PAYLOAD CAPABILITY TO NON-HRST GUIDELINE ORBITS (FOR HRLV VEHICLES OR SYSTEMS)**
  - _________ KG PER LAUNCH, DELIVERED TO 250 NM, 51.5 DEGREES
  - _________ KG PER LAUNCH, DELIVERED TO 100 NM, 90 DEGREES
  - _________ KG PER LAUNCH, DELIVERED TO GEO TRANSFER ORBIT
  - _________ KG PER LAUNCH, DELIVERED TO ______________________________
- **CHARACTERIZATION OF VEHICLE SYSTEM "SCALABILITY" (GREATER/LESSER PAYLOADS)**
  - *Describe "scalability"; provide attachments or references to relevant larger/smaller systems using the same basic conceptual approach; provide additional sheets as required.*

Using Standard 15% of Mass Design Margin

Data Reference: NAME, Org., Phone, Fax, e-mail

3 of 8

HIGHLY REUSABLE SPACE TRANSPORTATION

VEHICLE SYSTEM / TECHNOLOGY WORKSHEET

Form 4B (of 10)

• VEHICLE SYSTEM / COST DATA SUMMARY

ITEM	MASS (kg)	OVERALL MATURITY/DIFFICULTY TRL LEVEL [1-9]	DDR&D LEVEL [A-B]	MECH COMPLEXITY [1-6]	% NEW DESIGN [1-7]
STANDARD HRLV ELEMENTS/SUBSYSTEMS					
VEHICLE ACTIVE SUBSYSTEMS/ELEMENTS					
AVIONICS	TBD	TBD	TBD	TBD	TBD
LANDING GEAR	TBD	TBD	TBD	TBD	TBD
AERODYNAMIC CONTROL SURFACES	TBD	TBD	TBD	TBD	TBD
ON-BOARD ELECTRICAL POWER	TBD	TBD	TBD	TBD	TBD
OTHER MECHANICAL/FLUID SUBSYSTEMS	TBD	TBD	TBD	TBD	TBD
OTHERS?	TBD	TBD	TBD	TBD	TBD
"PAYLOAD ACCOMMODATION SUBSYSTEMS/ELEMENTS"					
PAYLOAD BAY DOORS	TBD	TBD	TBD	TBD	TBD
PAYLOAD BAY	TBD	TBD	TBD	TBD	TBD
OTHERS?	TBD	TBD	TBD	TBD	TBD

Use additional Sheets as needed to describe specific technologies

Baseline _____ OR Enhanced _____ Mass Design Margin

Data Reference: NAME, Org., Phone, Fax, e-mail

HIGHLY REUSABLE SPACE TRANSPORTATION

VEHICLE SYSTEM / TECHNOLOGY WORKSHEET

- **VEHICLE SYSTEM NAME**
  - *Name*

- **OVERALL VEHICLE / SYSTEM TECHNICAL MATURITY (TRL LEVEL)**
  - TRL =

ASSESSMENT OF MAJOR SYSTEM ELEMENTS/SUBSYSTEMS:

(LIST ALL THAT ARE REQUIRED TO ADEQUATELY CHARACTERIZE PROPULSION SYSTEM)

- **ELEMENT/SUBSYSTEM NAME:** TBD (e.g., "Avionics")
  - Description [Text - approximately Š 200 words]
  -
  - Critical Technology Requirements (Text - list all that apply)
  - Current Element Technical Maturity (TRL Level) = ____________ [TRL 1 through TRL 9]
  - Projected Degree of Difficulty for R&D to Achieve TRL 6 = ___________ [DDR&D = A thru' D]

Use As many additional sheets as required ...

IF POSSIBLE, INDICATE HOW THIS SUBSYSTEM/ELEMENT WOULD BE OR HAS BEEN MODIFIED USING ALLOCATION OF INCREASED "MARGIN"

Data Reference: NAME, Org., Phone, Fax, e-mail

HIGHLY REUSABLE SPACE TRANSPORTATION

VEHICLE SYSTEM / TECHNOLOGY WORKSHEET

- **VEHICLE SYSTEM NAME**
  - *Name*

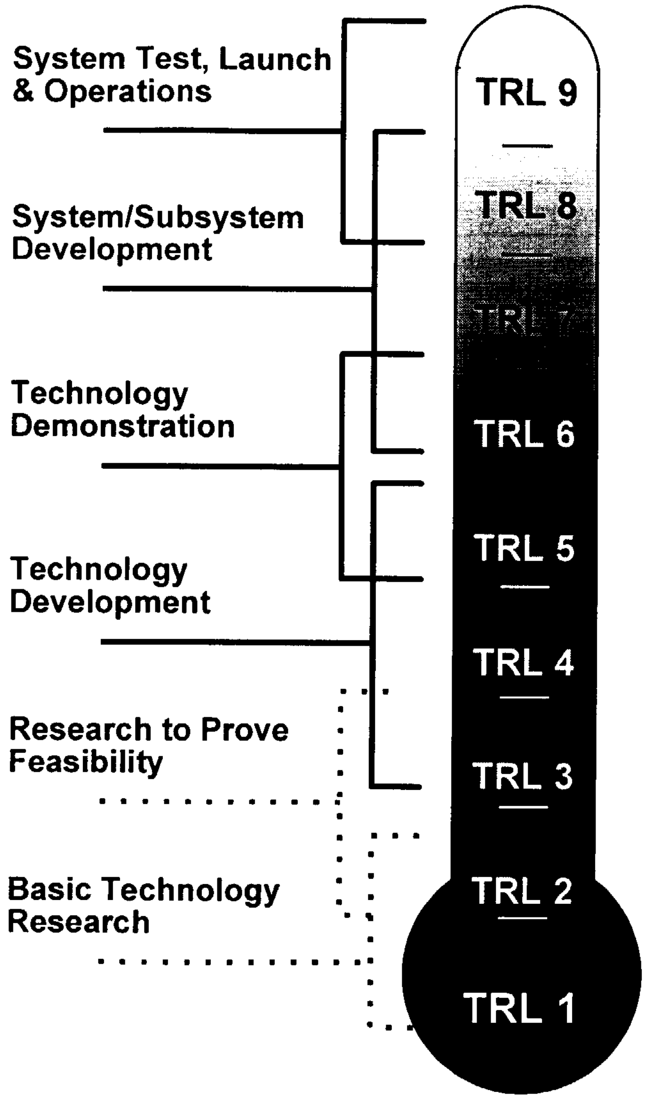
- **CHARACTERIZATION OF WRAP-AROUND COSTS**

ITEM	OVERALL TRL	OVERALL DDR&D	INHERITANCE) (HIGH/MED/LOW)
System Test Hardware	TBD	TBD	TBD
Integration, Assembly and Check-out	TBD	TBD	TBD
System Test Operations	TBD	TBD	TBD
Ground Support Equipment	TBD	TBD	TBD
Systems Engineering and Integration	TBD	TBD	TBD
Program Management	TBD	TBD	TBD
Other?	TBD	TBD	TBD

Data Reference: NAME, Org., Phone, Fax, e-mail

HIGHLY REUSABLE SPACE TRANSPORTATION

VEHICLE SYSTEM / TECH. WORKSHEET – TECHNOLOGY READINESS LEVELS



TRL 9	Actual system "flight proven" through successful mission operations
TRL 8	Actual system completed and "flight qualified" through test and demonstration (Ground or Flight)
TRL 7	System prototype demonstration in a space environment
TRL 6	System/subsystem model or prototype demonstration in a relevant environment (Ground or Space)
TRL 5	Component and/or breadboard validation in relevant environment
TRL 4	Component and/or breadboard validation in laboratory environment
TRL 3	Analytical and experimental critical function and/or characteristic proof-of-concept
TRL 2	Technology concept and/or application formulated
TRL 1	Basic principles observed and reported

REFERENCE

HIGHLY REUSABLE SPACE TRANSPORTATION

VEHICLE SYSTEM / TECH. WORKSHEET – DEGREE OF DIFFICULTY IN R&D

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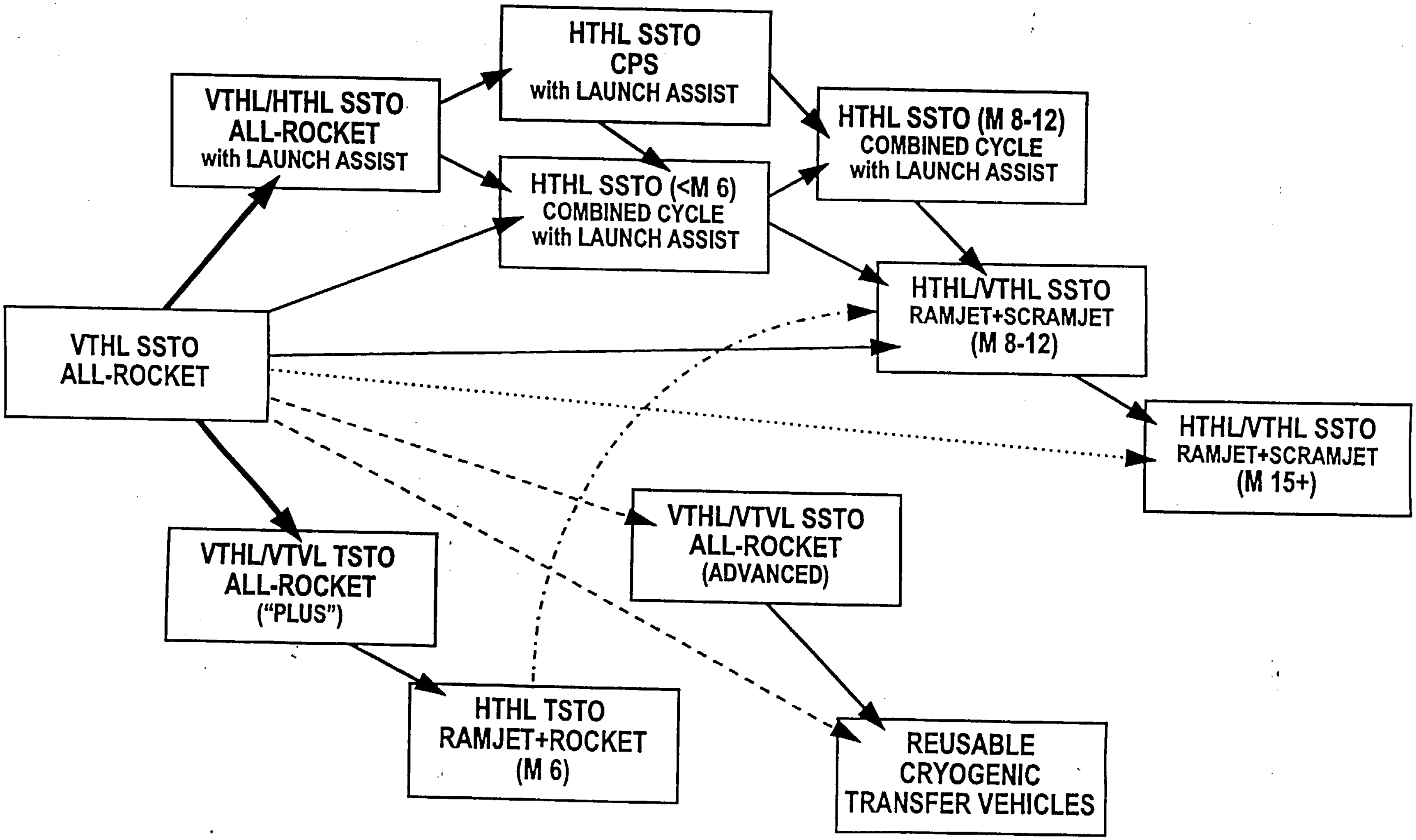
Technology Road Maps

Strategic Insight created structures for technology road maps of candidate HRST concepts by independently synthesizing a new way to display and summarize the existing technology ideas. The typical NASA approach, which is shown in following three charts from the April working group meeting, we felt to be not as useful for thinking about the various options presented by the full range of concepts. They are included here for completeness, however.

Our approach emphasized the collection of ideas into launch and landing operations (horizontal or vertical takeoff, horizontal or vertical landing) as a prelude to grouping specific technology ideas. This candidate structure for creating road maps was presented at the TIM in July; the charts themselves (noted as "HRST TIM - 1" through "HRST TIM - 12") are included for the record on the following pages.

A summary approach to creating the actual roadmaps themselves is also presented at the end of this section. This chart presents the logic of considering operational characteristics—a step along the way to developing actual roadmaps for individual concepts—in a graphic form.

PRELIMINARY HRST FINDINGS (1 OF 3)
NOTIONAL "TECHNICAL RISK ROADMAP" FOR HRST CONCEPTS



PRELIMINARY HRST FINDINGS (2 OF 3)
INTEGRATED HRST TECHNOLOGIES ASSESSMENT

CLASS I
<u>COMMON REQUIREMENT</u>

200-Plus Flight Life LOX-Hydrogen SSME-Class Rocket Engines

RBCC: Ramjet Mode

RBCC: Scramjet Mode (to Mach 8-12)

Electromagnetic Launch Assist (Magnetic Levitation/Propulsion, Power)

CLASS II
<u>HIGH-LEVERAGE</u>

RBCC: Supercharged Ejector Ramjet Mode

Advanced Propellants (e.g., Gelled H2)

Advanced Structural Materials

High-Temperature/Sharp Edge TPS

CLASS III
<u>CONCEPT-ENABLING</u>

Magnetohydrodynamic (MHD) Propulsion Systems

High-Power Microwave Wireless Power Transmission

RBCC: Mach 15+ Scramjet Mode

High By-Pass Ratio Turbofan

High-Speed In-Flight Cryogen Transfer

Air Collection and Enrichment

CLASS IV
<u>OPPORTUNITY</u>

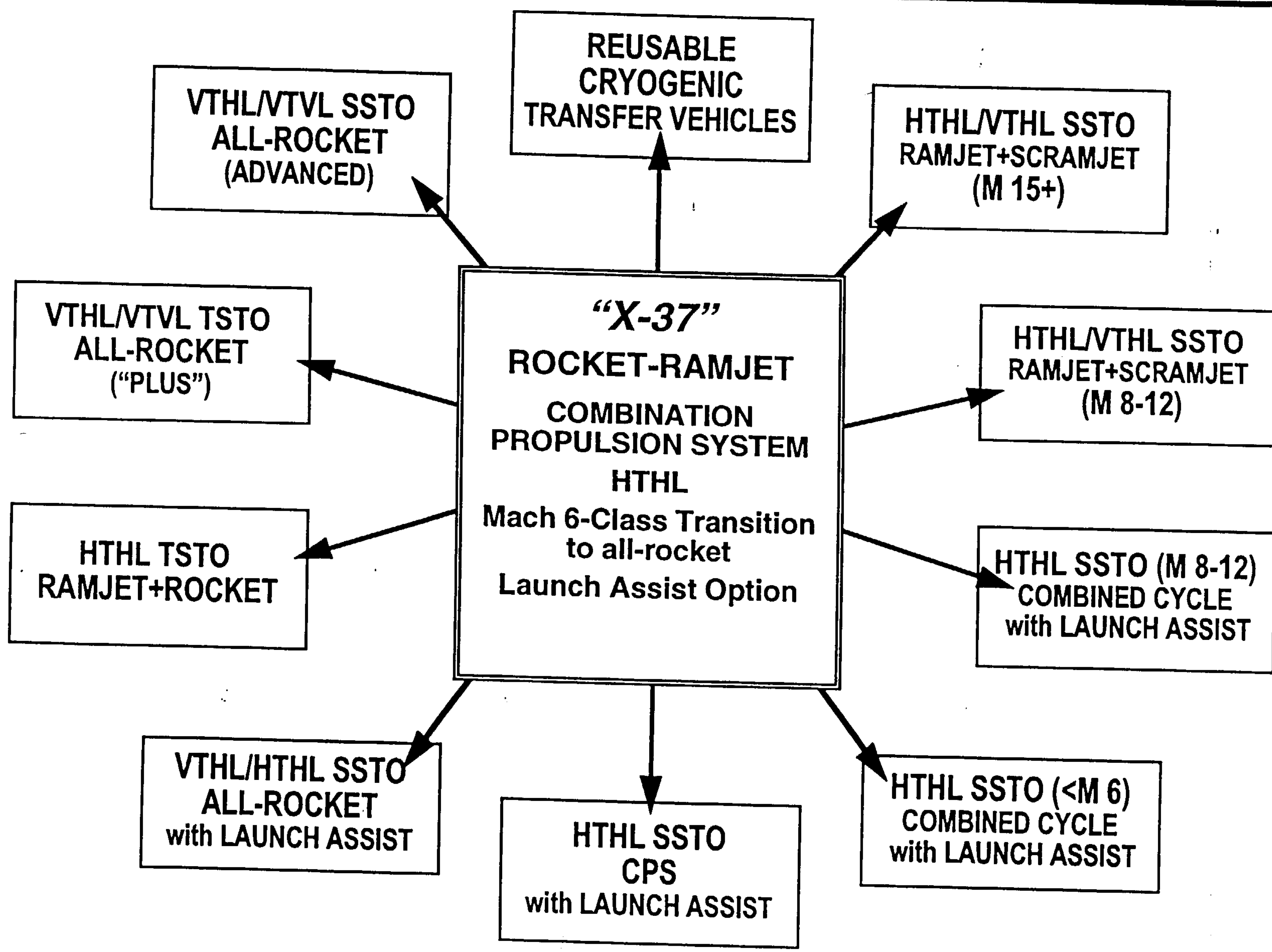
Ultra-Low Cost Rocket Engine

Oxygen Enrichment (e.g., Vortex Tube)

Waverider Airframe Configuration

Advanced Airframe Configuration (e.g., Funnel-Type Lifting Body)

PRELIMINARY HRST FINDINGS (3 OF 3, CONTINUED)
VERY PRELIMINARY RECOMMENDATION FOR "X-37" PLANNING



HRST-HITF Support

Technology Assessments Team

Creating Technology Road Maps

Strategic Insight

July 22-24, 1997

Discussion Topics

- Organizing Principles
- Operational Concepts
- Evaluation Criteria
- Technology Choices
- Roadmap Development

Organizing Principles

- **Roadmap organized around launch & landing operations**
  - Operations should drive roadmap generation rather than technology's driving operational concepts...
  - Operational concept creates a system-level structure that forces a fit of the technology to the need rather than NASA's making the assessment based on nice-to-have technology ideas

Operational Concepts

- **The Usual Suspects**
  - Horizontal Take-Off
  - Vertical Take-Off
  - Horizontal Landing
  - Vertical Landing
- **First-level grouping is needed for collecting study concepts**

Evaluation Criteria

- **Need a minimum number of criteria**
  - Assume OSAMs data will not be complete as technical evaluation begins
  - Use some questions to uncover technology "goodness"
    - Risk/Reward (Cost/Benefit)
      - Does the expected benefit of new technology outweigh the risks & costs associated with a low TRL?
    - What Costs/What Benefits?
      - What is it going to cost to impact mass fraction?

Technology Choices

- **Conduct technology cost/benefit to force a systems view into launch & landing concepts**
  - Evaluate how a certain technology can be integrated into—and provide value added to—a launch/landing concept
  - Corollary: Use some other technology to strengthen technology concept
- **Technologies should naturally group themselves**

The Roadmap

- Group technology by launch/lander concept and discuss vertically
- Conduct "first cut" cost/benefit analysis based on known data
- Evaluate TRL against development risk/cost
- Use "systems view" to uncover technologies that that cross multiple concepts or are concept enablers/ opportunities
- Prepare list of recommendations

HRST Concept Options Family Tree

- Vertical Take-Off/Vertical Landing
  - SSTO
    - Propulsion
    - Airframe
  - TSTO
    - Propulsion
    - Airframe
  - Launch Assist
    - Ground Launch Assist
    - Airborne Launch Assist
  - Vertical Landing
    - Propulsion
    - Airframe
    - Landing Concept
  - Infrastructure
- Vert. Take-Off/Horizontal Landing
  - SSTO
    - Propulsion
    - Airframe
  - TSTO
    - Propulsion
    - Airframe
  - Launch Assist
    - Ground Launch Assist
    - Airborne Launch Assist
  - Horizontal Landing
    - Propulsion
    - Airframe
    - Landing Concept
  - Infrastructure
- Horiz. Take-Off/Horizontal Landing
  - SSTO
    - Propulsion
    - Airframe
  - TSTO
    - Propulsion
    - Airframe
  - Launch Assist
    - Ground Launch Assist
    - Airborne Launch Assist
  - Horizontal Landing
    - Propulsion
    - Airframe
    - Landing Concept
  - Infrastructure

Technology Assessment Job vs. OSAMS

- **T. A. has a different charter**
  - Not competitive with OSAMS
  - OSAMS data was used initially
  - While OSAMS is comprehensive, we must develop a “cross-cut look that singles out technologies that represent the critical path for further R&D work

First Cut Ranking Parameters

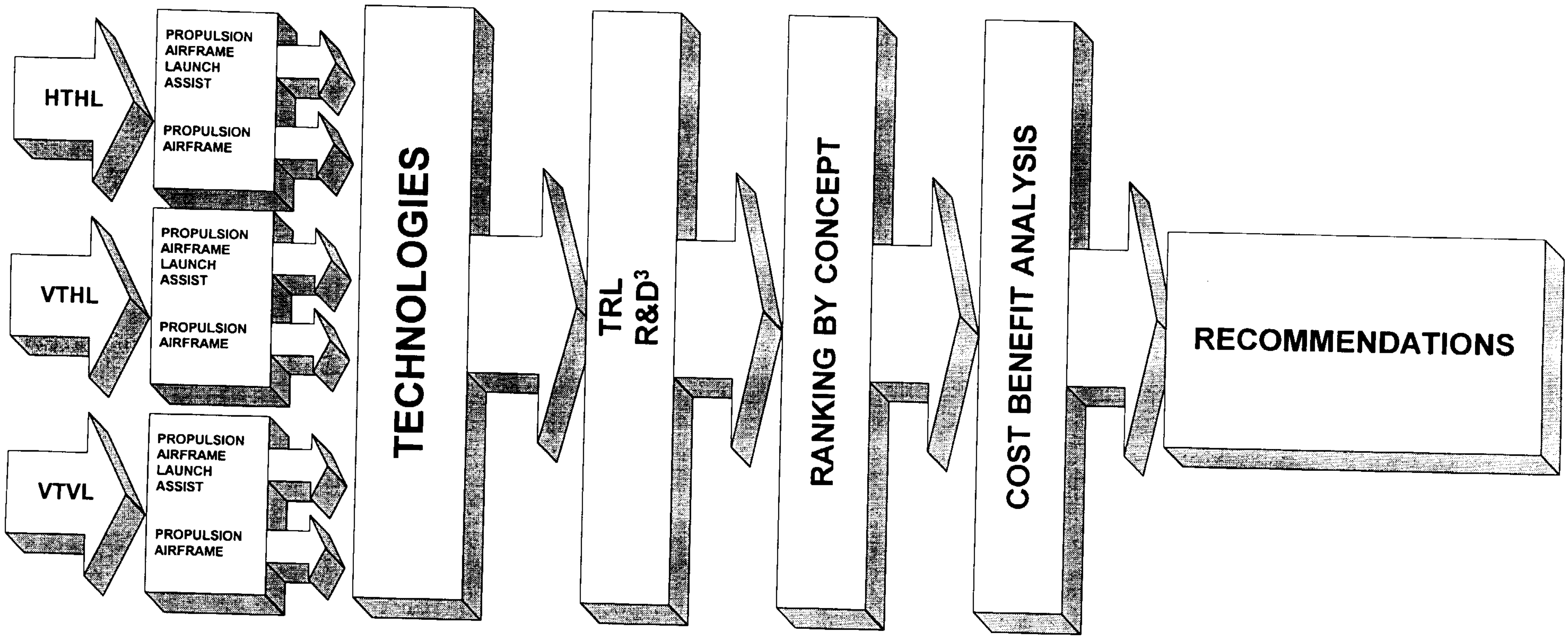
- **TRL/DDRE to readiness level 6**
- **Cost per pound of payload**
  - weight reduction impact
  - mass fraction /margin increase
- **Parts count/reliability**
  - reduced maintenance
  - lower production costs

Technology Assessment

- **Needs to identify all viable system concepts which include technology opportunities**
- **An analysis structure needs to be created to address:**
  - enabling technologies
  - maturity of system/subsystem designs
  - development difficulties ahead
  - other issues for DDR&D, if any

Technology Classes

- Common requirements
- High leverage options
- Concept-enabling
- Opportunities



STRUCTURE FOR TECHNOLOGY ROADMAPS

Summary

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298-102

In fiscal year 1997, Strategic Insight performed analytical studies for NASA's Highly Reusable Space Transportation (HRST) program, creating program documents which illuminated technical requirements and critical research opportunities. Studies were performed to structure and confirm HRST's evolving technical requirements, building on Marshall's Phase I work, which defined HRST system concepts, analytical tools and high-level issues for assessment in Phase II.

Specifically, Strategic Insight:

- performed a requirements analysis to update "HRST: *An Advanced Concepts Study* -- Study Guidelines, Version 2.0 of January 22, 1996; only minor changes were recommended for the given parameters of interest to concept designers.
- conducted mini-workshops during HRST Working Group meetings on April 14-15, 1997 and July 22-24, 1997; and,
- created structures for technology road maps of candidate HRST concepts—both subsystem and end-to-end concepts—emerging from the 13 cooperative agreement projects.